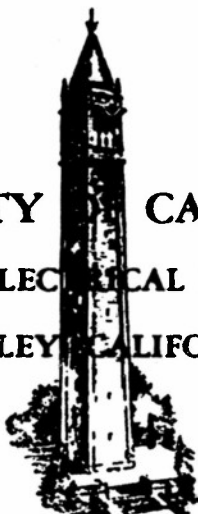UNIVERSITY CALIFORNIA

DIVISION OF ELECTRICAL ENGINEERING

BERKELEY CALIFORNIA

ELECTRONICS RESEARCH LABORATORY

QUARTERLY PROGRESS REPORT
1 OCTOBER 1953–31 DECEMBER 1953

ELECTRONICS RESEARCH LABORATORY

Division of Electrical Engineering
University of California
Berkeley, California

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Prepared by:

J.D. Axtell, Jr.,

Approved by:

J.R. Whinnery

FORWARD

This Progress Report covers the research being done under Contracts
AF 33(616)-495, W 33(038)ac-16649 and N7-onr-29529, in effect with the
Electronics Research Laboratory. The report also includes, in Sections X
and XI, descriptions of some of the University-supported research which is
actively being pursued at the present time. This material has been includ-
ed in order to give a more complete picture of the total program of the
Electronics Research Laboratory.

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W.H. Watson

1.1 Backward-Wave Interaction Studies

Summary of Previous Work

The original purpose of this investigation was to explore the possibilities of utilizing the higher-order modes and space-harmonics which exist on a tape helix for useful interaction with an electron beam. Using the work of Sensiper[1] as a basis, the tuning curves and electronic impedances of several modes were calculated. The results showed that the $\left[h_{to} \right]_{-1}$ harmonic would be excellent for use in backward-wave tubes with a suitably designed helix and electron beam. Moreover the results indicated that other modes might find use in special applications. The calculations were described in a paper in January, 1953[2].

Although work was proceeding elsewhere in the development of the helix as a circuit for the backward-wave oscillator, it was decided to continue with the original plans and to build a tube whose characteristics could be correlated with the calculations. The tube was described in an earlier progress report.

Current Work

A modified backward-wave tube has been constructed. In this tube the helix is surrounded by nonex glass (i.e., it is loaded dielectrically). The coaxial-helix matching has been improved and the helix was designed to operate at a lower range of diameter-to-wavelength ratio. As a backward-wave oscillator, the tube tunes from about 1000 to 2000 Mc/sec. Operated both as a

1. Sensiper, S., " Electromagnetic Wave Propagation on Helical Conductors", Ph.D. Dissertation, MIT., 1951.

2. Currie, M.R., " Notes on the Impedance Characteristics of Modes on Helix", Unpublished Report, E.R.L., University of California.

forward and backward-wave amplifier, at least seven harmonics have been traced from 750 to 3200 Mc/sec. Although the tube does not possess an optimum design for a BWO, it yields several watts of r-f power over most of the band, and 13 watts output at about 7 percent efficiency have been measured.

A brief technical report will be issued in the ensuing quarter in order to summarize the helix calculations and their correlation with the measured results on the two tubes. The report will be based essentially on the original paper[2], and will complete this phase of the study.

The effort during the next quarter will be primarily directed towards the study of backward-wave amplification. In particular, below the oscillating point, a backward-wave tube operates as a high-gain, narrow-band, voltage-tunable amplifier. Preliminary calculations show that a two helix tube might yield a higher gain as well as affecting isolation of the output from the input circuit. In such a tube, an input helix would serve as a signal launcher. The modulated beam would then pass through a drift tube and induce an amplified output wave on the second helix. A theory neglecting helix loss and space-charge has been set up and calculations will be carried out in order to determine the general characteristics of this new device.

M.R. Currie

1.2 Space Charge Waves in a Finite Magnetic Field

Summary of Previous Work

Analyses have been made for interaction of a slow wave circuit with an electron stream when a finite magnetic field is present, with various orientations of the magnetic field. Experimental work is being concentrated on the magnetron type of interaction, with crossed electric and magnetic fields. Cold tests have been made on a zig-zag type of circuit for interaction with a ribbon beam, and a tube has been constructed for a d-c test of the beam focusing.

Current Work

In the d-c beam test, most of the beam is arriving at the rather small collector, but best focus conditions occur at a higher value of magnetic field than that given by $E = vB$. This probably arises from fringing fields at the entrance into the crossed-field region, and results in paths of cycloidal type.

Secondary emission also appears to be taking place from the horizontal plates. The details of the electron paths and secondaries will be investigated in more detail before the r-f circuit is included in the tube. Attempts are currently being made to make the r-f circuit of tantalum or molybdenum.

side view   top view
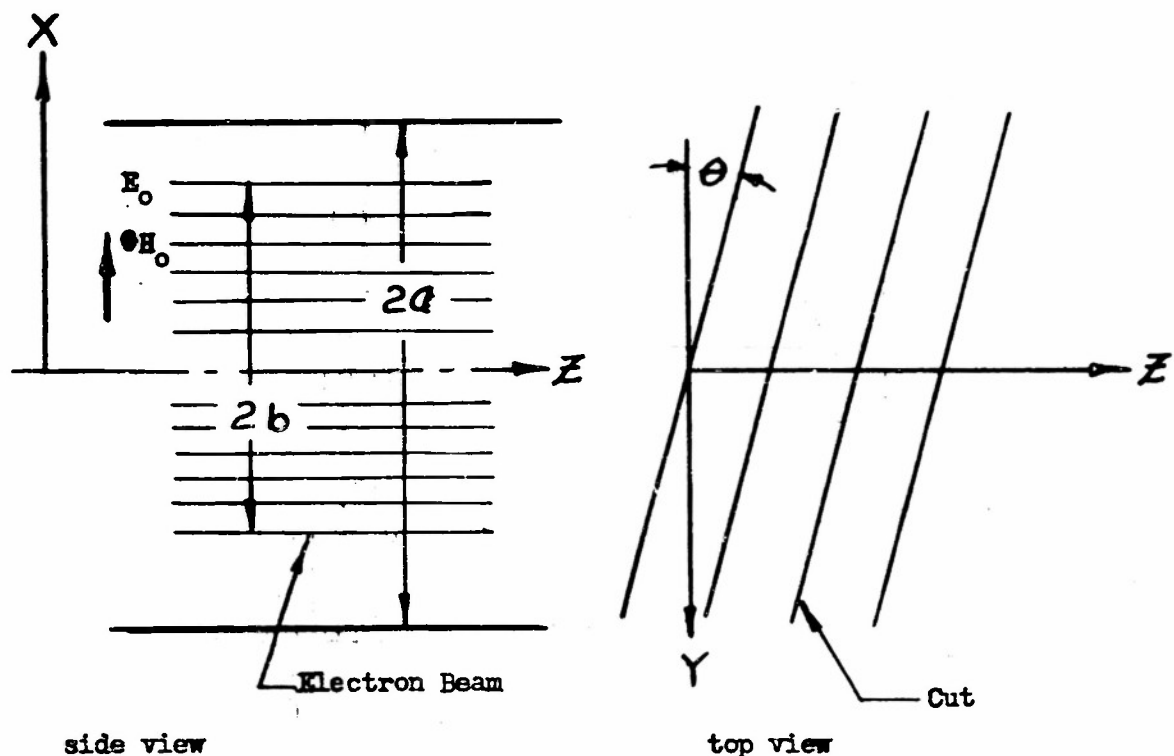
Fig. (1)

In the analysis for the basic model of Fig. (1) when the circuit phase velocity deviates from synchronism by a small quantity "d", then it may be easily shown, by an analysis similar to that made by Pierce[1] for the traveling wave amplifier with a longitudinal focusing field, that the gain for the magnetron amplifier as a function of the parameter "d" is described by concentric ellipses centered at the origin, if the magnetic field is large

1. Pierce, J.R., Traveling Wave Tubes, Van Nostrand, 1950

enough. This is shown in Fig. (2). The gain described by ellipse (1) for example is for a magnetic field larger than that described by ellipse (2). Also it may be shown that the growing wave has an initial value of one half the applied voltage instead of the one third value for the conventional traveling wave tube.

Having constructed Fig. (2) we are now proceeding to study backward wave oscillations in the traveling wave magnetron amplifier by an analysis similar to that made by Pierce for
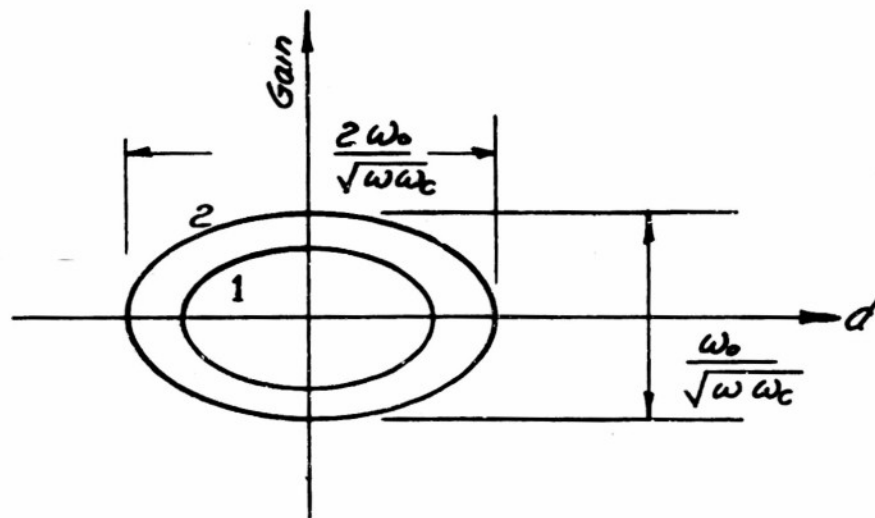
Gain as a function of the velocity parameter d. ω_0 is the plasma frequency, ω_c the cyclotron frequency and ω the operating frequency

Fig. (2)

the traveling wave tube with a longitudinal focusing magnetic field. We conclude from a simple computation that when the magnetic field is large enough, backward-wave oscillations are unlikely to occur in the magnetron amplifier. However when the transverse magnetic field is made zero our boundary value solution gives us a gain identical to that for the conventional tube except for a numerical factor, and therefore it is clear that for zero magnetic field, backward-wave oscillations are possible. Hence there must be an intermediate value of transverse magnetic field beyond which backward-wave oscillations will not occur. A graphical solution of the gain equation for different value of magnetic field shows that if

$$\left(\frac{2\omega}{\omega_o}\right)^{2/3} \quad \left(\frac{\omega_c}{\omega}\right) > 2,$$ then backward oscillations are unlikely.

As before, ω, ω_o and ω_c are the operating, plasma and cyclotron frequencies respectively.

Thus one may conclude that the focusing magnetic field makes the operation of the traveling wave magnetron tube more flexible than that of the conventional traveling wave tube. One may control the gain, stability and signal to noise ratio by varying the magnetic field, while keeping the ratio of static electric to magnetic fields constant, so as to keep the electron velocity constant. Hence the need for developing circuits which are suitable for transverse interaction. Our plane zig-zag slow wave structure which we described in a previous report is one such circuit, and therefore deserves more detailed analysis.

S.S. Solomon

1.3 Helix Impedance Measurements

Summary of Previous Work

The object of this investigation is to study the impedance characteristics of a junction between a coaxial and a helical transmission line. In particular, it is desired to define a suitable characteristic impedance for the helix, and to determine the effect of the helix and junction parameters upon the input impedance as seen by the coaxial line. The primary interest is with right angle transitions from a coaxial line to a helix with an external shield. This type of transition is of importance due to its applications in traveling wave tubes.

The method used until now has been that outlined by Storer, Sheingold and Stein[1], resulting in the scattering matrix for the junction, or an equivalent network. The shorting medium used on the helix was a mercury bath, and input measurements were made on a slotted line. Many points have been measured, but there is some question as to the result as they appear to violate the Foster reactance theorem.

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1. Storer, Sheingold, and Stein, " A Simple Analysis of a Two Part Waveguide Junction", Proc IRE Vol 41. No. 8 pp 1004-1013, Aug. 1953

Current Work

In this past quarter, a considerable number of additional measurements were made using the Storer technique. Also, a certain number of measurements were made using the Weissfloch tangent method[1]. The results of these measurements have indicated the possibility of certain limitations in this approach imposed by the experimental accuracy. As with all measurements of this type, a fundamental difficulty is due to the fact that a slight error in a distance measurement may cause a very large error in the equivalent circuit. Because of the limitation on accuracy no conclusive interpretation of measured results will be given.

To improve the accuracy, special precautions have been taken to improve the dimensional accuracy of the helices under test. In addition, the measurements are being made as close as possible to the junction. It is proposed to continue along this line, and to determine if other limitations may exist in the use of this approach.

W.H. Watson

1.4 Large Signal Study

Summary of Previous Work

It has been planned to measure build-up of signal along certain traveling wave-tubes under large-signal operation. For this purpose preliminary studies have been made of helix-type tubes of conventional type, and also with circuits outside the glass.

Current Work

The automatic device for Pierce-gun design is being completed. A frequency-sweep system for the study of matching is also being considered, as a large amount of time has been spent recently in developing matches to the tubes under consideration. It is planned to use a coupled helix system in the near future, as the coupling element following the work of Lacy of the Hewlett-Packard Co.

R.L. Hess

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1.   Marcuvitz, N., Waveguide Handbook, MIT Radiation Laboratory Series.

1.5 Electrostatic Focusing

Preliminary investigations have indicated that it should be possible to use cylindrical drift tubes to form beam focusing lenses in a velocity-jump amplifier. Combining the universal beam spread curve of Pierce[1], the requirement that velocity jumps occur each plasma quarter-wave length for amplification, and the focusing properties of cylindrical lenses, neglecting space charge, designs can be arrived at for velocity-jump amplifiers which indicate bandwidths and gains large enough to merit further investigation. A d-c model has been proposed and at present an electron gun to produce a converging axially symmetrical electron beam is being designed for use in testing this model and other possible focusing structures.

Emphasis however, will be placed upon the general problem of focusing high density electron beams rather than upon designing specific focusing structures.

W.M. Mueller

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1. Pierce, J.R., Theory and Design of Electron Beams, D. Van Nostrand Co. Inc., 1949 pp 150.

II. HIGH POWER MICROWAVE TUBE

Contract Numbers
W33(038)ac-16649
AF33(616)-495

Prof. D.H. Sloan
A. L. Gardner
D. H. Goodman

2.1   Model S-7 10.7 Cm. Resnatron

Summary of Previous Work

Various styles of tube geometry have been studied in the past and the
current arrangement has been designated the S-7 resnatron. For ease of modi-
fication, the tube employs a copper gasket between hardened steel flanges
which may readily be unbolted for disassembly. The S-7 designation has been
retained although several major modifications have been made, the last of
which involved replacement of the complete anode section. The tube utilizes
axial flow from an annular oxide cathode of about 40 cm^2 area, and is design-
ed for about 120 KV plate voltage. The tube is of the tetrode type with
grounded grid. The original anode had coupling which made it difficult to
match into a waveguide and load, but even with this anode, and a badly warp-
ed cathode which was only partially useful, one megawatt output power was
measured into a resonant load.

Current Work

The present anode has an adjustment to provide proper matching to the
impedance of the output waveguide. Since the previous report, construction of
this new anode has been completed. In cold test, the impedance matching ad-
justment performed in a very satisfactory manner. The frequency tuning ad-
justment was found to have some internal obstruction, of undetermined nature,
which prohibited tuning to frequencies below 2800 mc. Testing will therefore
be done with a 2J31 magnetron as a driver, since the anode cavity can still
tune from 2800 to beyond 2860 mc.

The tube was assembled and baked out, but during the bakeout one end
of the glass envelope cracked in several places and three leaks opened in

metal parts of the anode. These leaks were closed with glyptal and it was hoped that test run might still be made without re-glassing, but further vacuum troubles have prevented testing to date.

The glass-to-kovar seal where the cracks occurred was designed to transmit less strain from the steel flange than did the preceding model, nevertheless the cracking was more severe. The heating and cooling times will be considerably increased during future backouts in order to give a greater degree of protection to the glass.

An r-f load which matches the waveguide output has been constructed and cold-tested. It employs a water U-channel in a lucite rod. The rod extends through a short and narrow oil-filled section of waveguide which is clamped to the output window. The window itself is immersed in oil. The determination of the effectiveness of this load under high peak powers will come during actual use.

A.L. Gardner

2.2 Field Emission Tube

Summary of Previous Work

The field emission tube is designed to investigate the possibilities of obtaining a density modulated electron stream by controlling the number of electrons actually leaving the cathode, rather than producing the variation in electron density along the beam through a low level velocity modulation and a drift region or by control of a space charge. Due to the exponential nature of the field emission it may be possible to achieve rather large ratios of electron densities along the stream.

As indicated in the last quarterly report a system was devised whereby the d-c potential applied to the tube was modulated by a 1000 cycle square pulse. This was superimposed on the d-c. A system of this type makes it possible to measure only the change in r-f power transferred through the tube. That is, the steady state component of r-f is eliminated from the detection system. Using this system an increase in output level of 20 db was obtained. Theoretical calculations on the point of operation of this tube are in quite good agreement with the results obtained during its short period of operation, i.e. the calculations show that best operation should be obtained at transit angles of approximately 1.45π radians; this operating point was found to have a transit angle of 1.59π radians at a frequency of 2750 mcs.

Unfortunately, the tube was unstable and the emitter was destroyed and very
little data were obtained. The reasons for this are unknown, although it is
surmised that the current became large enough to heat the emitter and change
its emission characteristics; a second possibility is the result of ion bom-
bardment.

Current Work

Several razor-edge emitters have been placed in the tube and tested.
In all cases the emitters have shown signs of melting when they have been re-
moved. Pulse techniques have been used and operation of the tube has been
obtained. Again, however, the operation has been over very short periods
and the data obtained is not completely conclusive.

During the next quarter it is planned to try more razor-edge emitters
under more controlled conditions in an attempt to stabilize operations.
Point emitters will also be tested.

D.H. Goodman

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III. HIGH DENSITY CATHODE STUDIES

Contract Numbers
AF33(038)-ac-16649
AF33(616)-495

Prof. D.H. Sloan
T.E. Bowman
C.R. White

3.1 Arc-Cathode Studies

To build a nearly indestructible cathode capable of giving high current density emission, the plasma of a bismuth arc is being investigated. Small holes, drilled in the wall of a hollow anode of an arc, will receive electrons from the plasma and let them travel through to the region outside, where a high vacuum can be maintained.

Recent experiments have been made with a tin vapor arc because it allows a wider range of temperature above melting before the vapor pressure is too high to be called high vacuum. Using tin vapor, with a plasma current density of 0.8 amp per cm^2, a current of 0.8 amp / cm^2 was extracted thru a quarter inch diameter hole in the arc anode. The tin vapor pressure outside was negligible and a small graphite anode placed outside the hole was easily raised to 13 KV. The current through the hole rose sharply with increasing voltage, up to about 1000 volts, above which no further increase of current was obtained. The saturation was as clear cut as in the case of emission from a tungsten filament.

Next, another graphite disc with a 3/8" diameter hole was placed between the high voltage anode and the hole of the arc anode. This disc acted as a control grid. The triode thus formed was connected as a Hartley oscillator and gave about 50 watts at 6 mo with an input of 200 watts d-c. Before good adjustments or measurements were made, the device failed because of dielectric heating of lavite mounting bushings.

Instead of building a better oscillator, attention was fixed upon getting a higher density of current in the plasma. Many geometric arrangements were tried and pulses of 50 volts and 2000 amps were applied to the arc anode, giving current densities of 40 amps / cm^2.

During these tests it was noticed that after one or two hours of operation a new batch of tin became contaminated and no longer gave a smooth flow of vapor, but instead, also emitted a spray of molten tin drops up to 1/16" diameter, quite similar to the spatter of steel drops thrown out by ordinary steel arc welding at atmospheric pressure.

These hot tin drops were so disturbing that the tests are now being continued with bismuth, which has not yet displayed this feature. Closer control of electrode temperature is needed with bismuth.

D.H. Sloan

IV. SLOT ANTENNAS

Contract Number
N7-onr-29529

Prof. L.J. Black
Prof. L.E. Reukema
G. Held
G.K. Tajima
H. Unz

4.1 Non-Resonant Circular Slots in Various Ground Plane Shapes

Summary of Previous Work

This study is concerned principally with the behavior of the admittance characteristics of large-surface antennas of circular symmetry having a circular slot.

A spherical antenna fed by a narrow slot at the equator was first investigated. The quasi-theoretical admittance was obtained by utilizing a static capacity measurement in conjunction with a mode expansion solution. Experimental results were made on a hemisphere 17 cm. in diameter, over a frequency range of 300 to 1500 mc, using a Chipman measuring line.

The second configuration investigated was the biconical horn of large cone-apex angle. The Schwinger variational method was applied to obtain the theoretical result. The solution for the admittance appeared in two parts; one part corresponding to a spherical antenna, and a second part constituting a correction term for the removal of the spherical surface. Since the spherical antenna admittance had already been evaluated, the additional computation involved only the determination of the correction term.

Another antenna studied was the circular disk. The theoretical result was obtained by a perturbation of the results for the biconical horn. Experimental results have also been obtained. A secondary problem arising out of this antenna is the analysis of the junction between a coaxial line and a radial line. An equivalent circuit representation was developed and the circuit parameters determined from measurements.

Current Work

In all of the above work a basic theoretical assumption is that the higher order modes in the biconical line leading to the slot have negligible effect on the admittance. A theoretical expression has been derived which gives a measure of the error involved in this assumption. This error is seen to be small for large cone-apex angles; the error approaching zero as the apex angle approaches 180°.

Computations have been started on the biconical horn and disk admittances and are nearing completion. The convergence of the admittance series is rather slow but it has been found possible to place an upper bound to the neglected remainder of the series for apex angles of 80° or less, and it seems probable that this can be extended to larger angles.

Further measurements have been made on the circular disk antenna and on a biconical horn.

The preparation of the final report on this study has been started.

G.K. Tajima

4.2   Internal Coupling between Longitudinal Wide Slots

The problem of coupling between two longitudinal wide slots, located in the broad face of a waveguide (TE_{10} mode) has been started during the past quarter. This problem is important in connection with broadband slot antennas. The study concerns the mutual impedance between the two wide slots as a function of their longitudinal spacing, as well as an equivalent circuit representation. A study of the available literature has been made, and the experimental investigation has been started.

As the external coupling between longitudinal slots may be neglected, our main concern is with the internal coupling between slots. In order to make possible the measurements of the power radiated from the wide slot, as well as to induce power into the slot, we used a second perpendicular matched waveguide so that the scattering effect will be equivalent to the scattering effect of half space.

A resonant wide slot (length $\frac{\lambda}{2}$, width $\frac{\lambda}{4}$) was cut in one side of the broad face of a horizontal waveguide. A relative position was found between the slot and the half-space equivalent waveguide. This relative position

was found to be symmetric with respect to the transverse axis of the slot, and asymmetric with respect to the longitudinal axis. The difference between the half-space and its equivalent matched waveguide is of the order of 1 db, with almost no phase shift. The working frequency was 9375 mc (λ = 3.2 cm). For an open slot, changes in the frequency of the power supply result in a change of scattering of the order of 1.0 db over a long period of time, and of 0.2 db over a short period. As the changes due to frequency change are of the same order as this difference, we may consider the slot radiating into the equivalent waveguide the same as a slot radiating into free space.

Equivalent circuit parameters of the above structure have been measured. Methods of measuring the mutual impedance between two wide slots, as well as equivalent circuit representations, have been considered. It is intended, for the next quarter, to build two wide slots, each with equivalent matched waveguide and with various resonant spacings and to measure the mutual impedances between them.

H. Unz

V. MULTI-MODE STUDIES

Contract Number
N7-onr-29529
Prof. S. Silver+
Prof. J.R. Whinnery
G. Held
W.H. Kummer

5.1 Multi-Mode Excited Slots

Summary of Research

This study, of narrow half-wave slots at various positions in the wall of rectangular waveguide which supports free propagation of the TE_{10} and TE_{20} modes, has now been finished, and a complete technical report is being prepared.

The impedance and mode-coupling characteristics of longitudinal and transverse half-wave slots in the broad face of the waveguide have been investigated, at constant frequency, as a function of slot position and of slot width. The properties of single slots have been used as a basis for the design of simple arrays. Instrumentation has been a large part of the research, and means have been developed for the generation, detection, and measurement of the separate modes in the waveguide.

The experimental setup for measuring slot patterns was designed so that the two-mode waveguide suffered no discontinuities or bends. All the patterns for the single slot at different positions had identical envelopes, the amplitudes being different due to different coupling between guide modes and slot. The patterns were identical to those of a half-wave dipole.

The radiation pattern for a two-slot array has also been computed and measured.

W.H. Kummer

+ Prof. S. Silver is on sabbatical leave, but is in contact with all the work under his direction.

5.2   Scattering by a Slot Radiator in a Multi-Mode Waveguide

Summary of Research

This study is concerned with the determination of the effects of a
slot radiator in the wall of a waveguide that can freely propagate several
modes. The work is now finished, and a complete technical report is being
prepared.

The first part of the research is an evaluation of the fields induced
in a longitudinal slot by an arbitrary, but given, exciting field. This is
done by first assuming a certain field in the slot, and then finding the
scattered electromagnetic fields that would be produced in both the regions
that are external and internal to the waveguide. Applying then the boundary
conditions on the fields over the slot yields a condition that relates the
assumed field in the slot to the exciting field. This condition appears
in the form of an integro-differential equation for the voltage on the slot.
The formulation of the scattered fields is similar to the method indicated
by Leantovitz and Levin for wire antennas, and by A.F. Stevenson for slot
radiators.

In formulating the scattered field, asymptotic expressions are sought
for the Green's function of the external and internal regions. These are
found in the form of a part that represents the singularity of the electro-
magnetic fields at the source points, and in addition, a term that represents
the nature of the field at large distances from the source point. This cor-
rection appears in a form that represents directly the specific nature of
the multimode guide.

Having determined the induced voltage, the scattering by the slot in-
side the multimode guide is evaluated, and a general expression is found for
the terms of the scattering matrix.

Finally, the developed theory is applied to the case of a double mode
guide that has been investigated experimentally by W. Kummer. Agreement
between the theoretical and experimental results is remarkably good.

G. Held

VI. DIFFRACTION, SCATTERING, AND MICROWAVE OPTICS

Contract Number
N7-onr-29529
Prof. L.J. Black
Prof. S. Silver+
Prof. J.R. Whinnery
J.S. Honda
.G. Jeromson
R. Plonsey

6.1   Scattering From A Prolate Spheroid

Summary of Previous Work

This problem is primarily a study of the scattered field from a pro-
late spheroid illuminated by an incident plane wave. The main problem has
been the instrumentation. Since the scattered field is very small compared
with the incident signal, the null method has been used to measure the scat-
tered field. For this technique, a balancing mechanism and a frequency-
stable high-power signal source are required. Several watts at 9375 mega-
cycles have been made available by using a stabilized klystron oscillator to
drive a Varian V-27 two cavity klystron amplifier.

A balanced microwave bridge using a magic tee has been used to detect
the back-scattered signal. This system was highly frequency sensitive and
required a very critical balancing mechnism. A directional coupler having
large coupling and high directivity is now used in place of the magic tee.
Analysis and experimental work indicated that the directional coupler used
as a reflectometer is less frequency sensitive than the magic tee.

Current Work

In both microwave bridge methods, the received back-scattered signal
indicates that multiple scattering is present. In using the directional coup-
ler as the bridge, and if the calibrating object is pulled directly away
from the transmitting and receiving horn, the received back-scattered sig-
nal varies from a maximum value to a minimum value in approximately quarter
wavelength intervals. When the sphere is used as the calibrating object,

+See page 16

the minimum value approaches zero signal level. However, if a cylinder is used as the calibrating object, the interval of variation of the maximum remains the same, but the amplitude of the varying signal is a small fixed value relative to the received signal. This seems to indicate that the backscattered signal from the sphere is comparable to the multiple scattered signal while the scattered signal from the cylinder is large relative to the multiple scattered signal. In the next quarter an investigation must be made to find out why the multiple scattered signal is so large compared to the direct back-scattering for the sphere and not for the cylinder.

J.S. Honda

6.2 Beam Shaping Antennas

Summary of Previous Work

This is an investigation of the diffraction phenomena of cylindrical reflectors, for the production of shaped beams. The object is to improve the design techniques now available, but the methods of analysis, which it is hoped to develop, will not necessarily be so restrictive.

Preliminary diffraction studies, including experimental work, were made on an open waveguide between parallel plates and subsequently on the field of a pillbox fed by an open guide at the center of the aperture plane. The most significant result was that the near zone field of the pillbox was determined primarily by the diffraction effects of the feed blocking, and by the aperture edge. The results imply that the near zone field is invariant, to a large extent, with respect to the aperture field.

Theoretical investigations have also been conducted along lines of getting improved representations for currents induced on the reflector surface, thereby improving the far field calculations. To accomplish this, an investigation of various types of asymptotic series was made. Additionally, attention was directed toward analysis of simple cylindrical shapes in order to lay the basis for an attack on more general shapes.

Current Work

It was hoped that asymptotic solutions could be applied to obtain current distribution on the reflector. Comments on existing asymptotic solutions are included in the report of G. Jeromson[*]. The work of Moullin[3] is

*See 6.3 next page

- 19 -

valuable in giving an analytic solution for currents on a conducting strip. The basic interest lies in the distribution of current near the edge where deviation from geometrical optics is greatest. Moullin showed that the disturbance due to an edge is substantially contained within a width of $1/8\lambda$.

Turner[4] considers an open circularly cylindrical reflector on which there is an incident plane wave. He sets the far field in an integral form – and, following Papas[5], obtains the fields by use of a variational technique – based on the invariance of an expression for the field with respect to small changes in the induced current. This technique seems too complicated to have much significance for a more general problem.

Fock[6] sets up a similar integral equation except a vector three dimensional one, and seems to obtain very satisfactory results (see Riblet[7]) for closed convex surfaces. It would appear that since the geometrical optics current involves replacing the reflector with an infinite tangent plane at a given point, a better result would be obtained by replacing the reflector, at a given point, with a regular figure with the same curvature – where the regular figure be one whose induced currents can be obtained analytically. Fock implies that this is satisfactory in the penumbra region – and he makes use of results for the paraboloid of revolution. It remains to put his results on a more rigorous basis – and to extend to open-concave surfaces.

Continued theoretical work is scheduled for the next quarter in an effort to work out some technique, analytic or empirical, that will be satisfactory for simple cylindrical reflectors. It will be necessary to obtain experimental data in conjunction with the theoretical investigations, · and

it is hoped that a parallel-plane two-dimensional experimental system can be designed and constructed in the coming quarter.

R. Plonsey

6.3 Diffraction Theory

Current Work

The purpose of this investigation, a new study started during the past quarter, is to obtain further knowledge of the nature of electromagnetic diffraction, approaching the problem, in this case, primarily from a mathematical standpoint.

The work, to date, has consisted largely of a careful appraisal of the existing literature, especially those works which deal with asymptotic solutions of Maxwell's equations. In this connection, methods devised by Kline[2] and Riblet[1] have received special attention.

Kline[2] obtained an asymptotic development for a sinusoidally-time-varying electric field by starting with Duhamel's theorem in terms of a plus solution, and integrating repeatedly by parts. The series obtained involves inverse powers of $i\omega$, and is shown to be truly asymptotic. However, while certain relations among the coefficients are determined, there does not appear to be any direct way of actually finding them; the resulting field configuration, due to a " pulse wave" front, would have to be known in advance.

Riblet[1], in the unpublished paper, " The Asymptotic Soluction of a Diffraction Problem" , attempted to find the currents on a conducting cylinder induced by an incident plane wave. His point of departure was an assumed " asymptotic" expansion for an electromagnetic field, of the form

$$\vec{E}^* = e^{ikL} \sum \left(\frac{1}{i\omega}\right)^n \vec{E}^{(n)}$$

$$\vec{H}^* = e^{ikL} \sum \left(\frac{1}{i\omega}\right)^n \vec{H}^{(n)}$$

where $\vec{E}^{(n)}$, $\vec{H}^{(n)}$ are independent of ω, and where

$$\vec{E} = \vec{E}^* e^{-i\omega t} \; ; \; \vec{H} = \vec{H}^* e^{-i\omega t}$$

The phase function L of the " scattered" wave is determined on the basis of geometrical optics, by ray tracing. $\vec{H}^{(o)}$ is also found using this approach, and the other $\vec{H}^{(i)}$ by means of recurrence formulas. Thus, since the zero order fields are identically zero on the shadow side of the cylinder, no correction will be obtained here, using Riblet's technique.

Similarly, near the edge of the illuminated portion of the cylinder, the method fails to provide improvement over the ray tracing approach. However, the procedure evidently has value over that segment of the illuminated area where geometrical optics yielded good results.

In connection with the above, Fock[6] has devised a method for computing surface currents for a smooth, convex diffracting body, in the region near the boundary of the geometrical shadow.

It is hoped that in the future, an asymptotic development can be devised which would explicitly include the boundary conditions. It is also planned to make use of Bremmer's[8] treatment of the aperture problem (in which he obtains an asymptotic development using operational methods) to obtain expressions for the near zone field of a circular aperture, for points off the axis.

G. Jeronson

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7. Riblet, H.J., Geometrical-Optical Currents, Final Report, Microwave Dev. Lab. Waltham, Mass.

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VII. DEVELOPMENT OF CARRIER-CONTROLLED-APPROACH COMMUNICATION SYSTEM ANTENNAS

Contract Number
N7-onr-29529

Prof. D.J. Angelakos
Prof. L.J. Black
Prof. G.L. Matthaei
R.W. Bickmore
F.D. Clapp

All the development work on these antennas has been satisfactorily completed, and the past quarter was spent in the preparation of three complete technical reports, covering in detail the results of the whole program. These reports were written by the date scheduled for the close of this phase of the contract work, November 30, 1953, but the issuance of these reports has been delayed slightly by the fact that there have been a number of reports, on other phases of the total research program of the laboratory, coming out at the same time. The reports on the CCA work are, however, now in process of being issued. The three reports cover:

(1)   the flush-mounted, omni-directional annular-slot antennas, including a section on matching networks for these antennas,

(2)   the flush-mounted, cardioid-pattern antennas, and

(3)   the semi-flush-mounted (horn-type), cardioid-pattern antennas.

VIII. BROADBAND RADIATING SYSTEMS AND ASSOCIATED NETWORKS AT MICROWAVE FREQUENCIES

Prof. D.J. Angelakos

G. Held

H. Judy

M. Korman

K. Malinovsky

D. Stinson

8.1 General

The desirability of making use of one antenna-line system for more than one frequency range leads to this study. Such a system consists of the following basic parts:

- a). Transmission line.

  The circular TE_{01} mode offers a possible solution.

  Multi-mode transmission systems. More than one mode of field configuration can exist in the same guide.

  The ridge-waveguide as a broadband line.

  The three types of transmission lines are to be considered and their properties compared.

- b). Antenna. The antenna behavior over the band of frequencies is to be investigated.

- c). Components. Such components as matching sections, directional couplers, transition sections etc., will be individually investigated and designed.

Work on several of the above areas is described below.

D.J. Angelakos

8.2 Multi-mode Directional Couplers

Summary of Previous Work

This is a study of waveguide directional couplers using rectangular waveguide propagating TE_{10} and TE_{20} modes simultaneously. It was decided to use longitudinal narrow slots in the broad face of the main waveguide. By

placing narrow slots parallel to the lines of current flow of the undesired mode, which cut current lines of the desired mode, each slot may be made intrinsically mode selective. This type of coupling aperture offers a minimum discontinuity to the undesired mode and gives negligible cross coupling between modes.

Current Work

This quarter has been spent building and studying directional couplers using $0.4"$ x $1.6"$I.D. waveguide as the main guide propagating TE_{10} and TE_{20} modes simultaneously. The auxiliary guide, into which energy is coupled as TE_{10}, is standard "x" band, $0.4"$ x $0.9"$I.D. waveguide.

The only design found practical so far to couple TE_{20} energy and reject TE_{10}, uses a parallel arrangement of waveguides. Two longitudinal slots were milled along the center line of the broad face of the main guide and spaced $0.973L$, where "L" is one fourth of the average of the guide wavelengths in each waveguide for the design frequency. The 0.973 factor is an empirical constant used in conventional two hole couplers. The auxiliary waveguide is placed off center so the slots will excite the TE_{10} mode in the auxiliary waveguide. A model of this type with a coupling of -22db has a 30db directivity over a ± 5 per cent frequency band. The TE_{10} mode rejection was 35db below the -22db forward coupling power level of the desired mode in this band. The operation of this type coupler for the desired mode is essentially the same as conventional two hole couplers except that the apertures used are narrow slots. The narrow slots minimize the electric polarizability which would couple to the strong electric field of the undesired mode. They also minimize the magnetic polarizability to the H field lines orthogonal to the slot (current lines parallel to the slot). This type of mode selective directional coupler design could easily be extended to binomial or other similar broadbanding arrangements.

In order to couple to the TE_{10} mode and reject the TE_{20} mode, a similar arrangement with the auxiliary waveguide centered on the main waveguide and using transverse (series type) slots could be used. In an effort to obtain the broadband properties of the reverse coupling "crossguide" type coupler, a coupler using a similar design has been built and a study is in progress. Because of the difference of guide wavelength in the main and

auxiliary waveguides, and the difference of the slots' coupling to the two waveguides, complexities are introduced which will be discussed in a later report. The most promising design uses slots placed longitudinally to, and on opposite sides of the center of, the main waveguide, with the auxiliary waveguide crossing at an angle not equal to 90 degrees. The centers of the slots are centered on the auxiliary waveguide and the angle of the auxiliary waveguide is such that the longitudinal distances between the slots in each waveguide are approximately equal fractions of the corresponding guide wavelength.

The relative merits of alternative TE_{10} coupler designs (rejecting TE_{20}) will be studied further. The effect of tolerances and dimensions will be analyzed in order to establish workable design information.

<div align="right">H. Judy</div>

8.3 Properties of Ferrites

Current Work

The purpose of this study which has been started during this quarter, is the evaluation of the components of the permeability tensor for various ferromagnetic materials, considering the effect upon these materials of variations in the magnetostatic field and the shape and size of the ferromagnetic samples. A knowledge of these materials will be applied to the development of broadband systems.

An evaluation of techniques most probable of yielding significant results has been made. Essentially three schemes were considered and two of them were decided to be feasible. One method consists of using a cylindrical cavity and is now being applied at the Hughes Research and Development Laboratories. A recent visit to these Laboratories has shown that the instrumentation difficulties inherent in this method have been largely overcome and that work is progressing quite satisfactorily. The writer also obtained some ferrite samples and information pertinent to his own experiment. The other method considered feasible is the one to be applied in our studies. It depends upon the fact that a non-coupling slot in a waveguide should couple if the slot is filled with a small ferromagnetic sample and a magnetostatic field is applied in the appropriate direction. A knowledge of the

exciting magnetic field in the waveguide and the induced magnetic field radiating from the slot should then be sufficient to determine the components of the permeability tensor of the material.

At the present time the work on this problem has been of a formal nature. However, it is expected that the next step, of collecting and assembling the experimental devices, will be undertaken shortly.

D. Stinson

8.4 Wide Band Microwave Components

Current Work

In the present period work has been started on the design and analysis of a wide band slot radiator array. After consideration of several possible approaches to the problem it has been decided to consider the possibilities cf a set of slots, tuned to different frequencies in the desired band, cut in a multimode guide. The idea is to employ a set of staggered tuned slots, analogous to standard low frequency techniques of broadbanding by staggered tuning.

It became immediately apparent that for any possible analysis, two fundamental problems have to be investigated first.

   a). The input impedance properties of a slot of arbitrary length-to-wavelength ratio;

   b). The coupling (mainly internally) of slots of arbitrary lengths. These two problems appear because at any given frequency in the band there will be one or more slots resonating; however, there will also be present several off-resonance slots. The off-resonance slot can be taken into account only if information is available on the above mentioned two problems. Unfortunately, to our knowledge, no reliable and comprehensive treatment of these problems is available in the literature.

G. Held

8.5 The Ridge Waveguide

Current Work

A study is being started to investigate broadband transmission in hollow

metallic waveguides. The purpose is to study several composite waveguide cross-sections of the ridge type, like multiple or progressive ridges, etc. Emphasis will be placed on the relative merits of the cross-sections to lower the cutoff frequency of the dominant mode and on the possible elevation of the cutoff frequency of the second order modes. Preliminary calculations are now in progress to determine roughly the areas of maximum interest. Cross-sections giving the greatest bandwidth will then be thoroughly analyzed and also experimentally investigated.

K. Malinovsky

IX. RELATED RESEARCH STUDIES

Contract Number
N7-onr-29529

Prof. L.J. Black
Prof. L. E. Reukema
Z. Kaprielian
J. Minushian
J.B. Humfeld
A.M. Serang

9.1 Metallic Delay Media - Discs

Summary of Research

This research study has been completed during the past quarter and a complete technical report is now being prepared. Given here is a general summary of the work done. The problem concerns the electromagnetic propagation characteristics of space arrays of aperture-in-metal discontinuities and complementary structures. This problem is of interest because of the desirability of using thin obstacles to achieve indices of refraction much greater or much less than unity. Although several interesting attempts have been made using a summation of scattered fields for the particular case of small circular apertures and discs, it was found that the most convergent approach is a transmission line representation.

It has been shown that for a plane wave normally incident on a two-dimensional array of apertures having two axes of symmetry (coinciding with the symmetry axes of the array) the problem of finding the admittance of the array can, by imaging considerations, be reduced to a waveguide problem involving an appropriate obstacle. The impedance of the complementary screen is easily found by the familiar scalar expression based on Babinet's principle. It is demonstrable that this scalar relationship is valid only if the screen possesses the type of symmetry stated above, and if the center-to-center aperture spacing is less than a wavelength.

Four types of media were constructed, each consisting of 18 sheets of 18" x 18" Alclad, 0.020" thick. Three were in a square pattern with aperture-to-wavelength spacings of approximately 0.15, 0.30 and 0.60, and a spac-

ing to wavelength ratio of 0.85. The fourth was a rectangular pattern with
aperture-to-wavelength ratio of 0.30. This perforated sheet medium has ver-
satility in that, if irradiated from the edges, it served as a parallel plate
medium with periodic slots in the walls. A fifth medium, an exact complement
of one of the square aperture patterns, was also constructed by hot pressing
discs on polyfoam.

For the three dimensional arrays, a convenient representation was found
to be a transmission line representing free space, periodically loaded by
the single screen admittances. This simple representation is possible only
when:

1) The successive layers of obstacles are aligned along the direction
of propagation,

2) The center-to-center transverse spacing is less than a wavelength
in the ambient medium, so that there is only single mode propagation through
the array, and

3) The ratio of longitudinal to transverse spacing is sufficiently
large to insure that there is no interaction between the storage fields of
successive screens, since such interaction is not accounted for in the cal-
culation of screen susceptance. For the symmetrical obstacles considered,
interaction is only negligible when the ratio is at least unity.

Although the removal of the second and third restrictions still make
the problem formally soluble, the general problem is difficult.

From transmission line theory, the definition of an equivalent index
of refraction and characteristic impedance was set up for loaded space in
terms of the screen susceptance. An expression for the susceptance of a
two dimensional array of circular apertures arranged in a rectangular pat-
tern was calculated variationally, and the result was a low frequency sus-
ceptance plus a correction term. While the first term gave results for the
refractive index identical with those derived by Kock from molecular theory,
the use of the correction factor gave transverse proximity effects and also
accounted for frequency. In this connection, it was suggested that the
transmission line theory is the more fundamental and a reduction to a molec-
ular mode was made under the usual spacing and wavelength restrictions.

A free space measurement technique was developed for the general thick
screen which gives the parameters of the equivalent T-network, and the re-
sults on experimental screens agreed closely with theory. Free space refrac-

tive index measurements on aperture and disc media were also made and gave
good results.

J. Murnushian

9.2 Metallic Delay Media-Cylinders

Summary of Research

This research study has also been completed in the last quarter and
a complete technical report is under preparation. The problem consists of
a study of the dielectric properties of a medium consisting of a series of
plane grids of conducting circular cylinders, for electromagnetic plane
waves, with the polarization vector parallel to and perpendicular to the
axis of the cylinders.

Four different approaches to the general problem have been employed
and the advantages, disadvantages and the realms of validity of each have
been studied. The first of these, the molecular model, is the most restric-
tive as regards wavelength and spacing by direct analogy with a completely
isotropic modecular media, wherein the propagating wave is plane throughout.
For H-polarization, this approach has been extended to account for dipole
interaction between elements of the array and leads to a two dimensional
Clausius-Mossotti relation for the electric polarizability. The second
approach deals with the loaded transmission line representation, which re-
moves the restriction on wavelength provided that there is still only single
mode propagation through the array. The restriction that the elements be
far apart in the longitudinal direction still holds, in that the susceptances
used are based on the assumption of the independent storage fields. The
third method, applicable for $kr_o \ll 1$, is based on the summation of scattered
fields for normal incidence on an interface, and leads to certain general
results which indicate that the Clausius-Mossotti relation, although a
good approximation, will not hold for close packing and high frequencies.
Therefore, consideration of higher order multipoles is essential. Finally,
to offer an analysis valid for all values of kr_o and spacings, an analysis
based on a variational method used in quantum mechanics of crystals, refor-
mulated from an integral equation point of view, was developed. This reformu-

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lation has the advantage of replacing the problem of choosing trial wave functions with that of choosing trial values of the currents on the obstacles at the lattice points. This method would be particularly useful when the obstacles are of such a shape that wave functions are not known. This approach can be extended to three dimensional geometries.

Experimental equipment was set up, consisting of a section of 10 cm. waveguide in which is an array of copper cylinders parallel to the broad faces. An almost continuous variation of spacing between the rods is possible. The index of refraction was found in the same way as for solid dielectrics. Within the range of guide wavelength, 10-20 cm., the index of refraction is constant with respect to wavelength within the accuracy of the measurement procedures. A free-space experiment was required to measure the characteristics for E-polarization, since this does not represent an infinite array if used in a wave-guide. A structure using lucite sheets perforated with 1/16 inch and 1/8 inch holes was built to support the cylinders. The free space interferometer, using a null method, was employed, and was also used for comparison with the waveguide method for H-polarization. Agreement between experiment and theory has been good.

Z. Kaprielian

9.3 Analysis of the Side-Outlet Tee for Impedance Measurements

Summary of Research

This study has been of the use of a side-outlet tee as an impedance bridge at microwave frequencies. The work has now been finished, and a report is being prepared.

In order to measure the sensitivity of the side-outlet tee to either the phase or the magnitude of reflection from a test load, a test load was devised such that its reflection coefficient could be varied in magnitude or phase, each independently.

A theoretical analysis of an asymmetrical tee was made. This analysis showed that the sensitivity of the tee to the phase of the test load reflection was due to the asymmetric coupling between the E- and H-arms, as well as the mismatch seen looking into the junction through the test arm. Further analysis established the theoretical relationships between the coupling and

reflection coefficients of junction arms and the phase and magnitude of reflection from the test load. From this analysis it was possible to devise the following means of removing the errors due to asymmetry and mismatch. These means were proven to be correct both by theoretical analysis and experimental work.

1) Using the H-arm of the tee as the input arm, the E-arm was coupled to a detector and the side arms to matched loads. If the tee had been symmetrical there would have been no power delivered to the detector. However, the tee was asymmetrical and therefore there was coupling between the H- and E-arms. In order to eliminate this, the load on the reference side arm was tuned until the E-arm detector received as little power as possible. In this way, the load on the reference arm was no longer a matched load, but it produced a dersirable minimum coupling between the input H-arm and the detecting E-arm. It was found possible to reduce the power delivered to the detector 65 to 70 db. below the input level. This, essentially, decoupled the E-arm from the H-arm.

2) With the test arm as the input arm, the reference load remaining as above, and a matched load coupled to the H-arm, the detector on the E-arm was tuned so that a match was seen looking into the junction through the test arm.

Experimental measurements were made with loads of the following three kinds:

1) Two loads having reflection coefficients of constant magnitudes (VSWR = 1.68 and 1.17), but varying phase.

2) A load having a reflection coefficient of constant phase but varying magnitude.

3) A load having a reflection coefficient which varied both in phase and magnitude.

The experimental measurements were made with the H-arm used as the input arm, the reference arm carrying the tuned reference load, the E-arm coupled to the tuned detector and the test arm coupled to the loads mentioned above. The measurements showed that the output to the detector was independent of the phase of the loads. The VSWR's measured with the tee were within 5 percent of those measured with a slotted line. This result substantiated, experimentally, the theoretical analysis which suggested the method of tee alignment described above. Thus the constructional asymmetry and mismatch

conditions in a side-outlet tee can be compensated for in such a way that the tee is insensitive to the phase of the reflection from the test load. The experimental results also verified the theoretical expectations that the power delivered to the detector is proportional to the square of the magnitude of the test load reflection. Thus a side-outlet tee can be easily calibrated, at one frequency, to use for direct measurement of the VSWR of any unknown load.

The side-outlet tee was tuned at 9440 mcs. with slide-screw tuners which were coupled to the necessary arms of the tee. These tuning elements made the tee extremely frequency sensitive. The effect of frequency variation was measured and it was found that for a frequency shift of $\pm$ 80 mc, the decoupling which was achieved between the input H-arm and the output E-arm was reduced from - 70 db to - 35 db. The VSWR seen looking into the test arm was increased from 1.02 to 1.5. This extreme sensitivity to frequency is probably due to the fact that the reactive tuning elements were not placed at the junction proper, and that these elements are themselves frequency sensitive. Thus a tee aligned and matched by use of slide-screw tuners is suitable for use as an impedance bridge for only a small frequency bandwidth.

A.M. Serang

9.4   Loaded Whip Antenna

Summary of Previous Work

This is a design and performance study of a 2-30 megacycle whip antenna with a high efficiency variable inductance as a center-loading element. The antenna can be tuned, either manually or automatically, from a control unit at the base. Two such antennas with mechanical means for varying the center loading inductance continuously from zero to maximum have been built here. Base impedance measurements were made at the large ground plane at the Navy Electronics Laboratory in San Diego. These measurements showed that high Q antenna systems are realizable for this frequency range using this type of antenna.

Current Work

The relative current distribution along the antenna has been measured. The current through the loading coil was seen to decrease sinusoidally, displacing that portion of the sinusoidal current distribution of a straight wire antenna replaced by the loading coil. The portion of the antenna below the loading coil was determined to have perfect sinusoidal current distribution corresponding to the same portion of a straight wire antenna a full quarter-wavelength in height. Confirmation of the current distribution allowed the calculation of radiation resistances and coil resistance referred to the base of the antenna.

Toward the close of the past quarter, a variation of the original shorted sleeve type variable inductor was constructed. The principal modification was to allow removal of the shorting sleeve from the field of the inductor.

J.B. Humfeld

X. SYNTHESIS OF BROADBAND MATCHING NETWORKS

University Sponsored Research

Prof. G.L. Matthaei

The object of this research is to devise more practical methods for synthesis of precision, broadband matching networks. This work was first begun under contract No. N7-onr-29529, in order to gain some idea of how much the size of flush-mounted circular slot antennas could be reduced by the utilization of matching networks. An example was worked out and the results are contained in a report now being issued in connection with the Carrier-Controlled-Approach antenna program. This program has now been satisfactorily concluded.

The present research is directed towards determining general methods for synthesizing low-pass, band-pass, or high-pass matching networks such as are often desired by the designers of electrical systems.

Fano[1] has made a contribution which clarifies the broadband-matching problem considerably. Utilizing insights obtained from Fano's work, this investigator has been organizing a general mathematical procedure which it is hoped will enable a designer to obtain the desired results with a minimum of labor. Methods involving continued-fraction expansions are found to expedite the synthesis process.

Some of the design examples presented by Fano require coupled coils. It has been noted that these coils become necessary because of the way in which he defines his reflection coefficient function for these cases. Work done here indicates that by a more flexible definition of the reflection coefficient function, coupled coils can be eliminated and better results can be obtained for a given number of circuit elements.

The present plans for this research are first to attempt to simplify the design procedure as much as possible when defining the reflection-coefficient function as Fano does. Next an attempt will be made to find computationally tractable ways of introducing more varied kinds of reflection-coefficient functions so as to eliminate coupled coils and obtain the best circuit efficiency. This last problem may be extremely difficult, since many more variables are involved. Iterative method, or possibly in-

1. Fano, R.M., " Theoretical Limitations on the Broadband Matching of Arbitrary Impedances", Journal of the Franklin Institute, Vol. 249, Jan. and Feb. 1950.

troducing small amounts of loss in the circuit, may give good results.

G.L. Matthaei

XI. CHARGE EXCHANGE ACCELERATOR

University Sponsored Research
Prof. J.R. Woodyard
Prof. D.H. Sloan
T.H. Koski
P.D. Compton++

Summary

The purpose of this project is first, a critical revaluation of the
basic principle of design of high-voltage d-c machines, making use of
modern high-voltage techniques, newly discovered circuits, recently available
materials, and the charge-exchange principle; and second, the application of
these principles to the construction of energy-doubling d-c accelerators to
produce 4 m.e.v. protons with 2 million volts d-c potential.

The method of attack used has been to first construct a quarter-scale
working model with 500 kv of applied d-c potential producing 1 m.e.v. protons
to establish the principles of operation and design.

Progress to date includes the design, construction, assembly, and pre-
liminary testing of the quarter-scale model· as well as the testing of two
basically new voltage-multiplying circuits for high-voltage rectifiers, d-c
tests of new high-voltage insulating materials, a study of high-voltage re-
sistors for metering circuits, and studies of two new types of cold-cathode
high-voltage rectifier tubes.

Introduction

The recent discovery of a method of producing large currents of negative
hydrogen ions has made practical, for the first time, an energy-doubling d-c
accelerator. When a beam of protons with an energy of around 30,000 electron
volts is sent through a thin foil about 100 atoms in thickness, approximately
20 percent of the incident protons capture two electrons each and emerge as
negative hydrogen ions[1]. Negative ion currents of the order of 100 micro-
amperes appear to be feasible with simple arrangements.

The negative ions produced in the capture fail are then accelerated by
a high-voltage d-c potential, next passed through a stripping foil where the
electrons are stripped off, reconverting the negative ions into protons, and

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++On Military Leave

1. Alvarez, L.W., " Energy Doubling in D.C. Accelerators," Rev. of Sci.Inst.
      Sept. 1951, p 705.

finally they are accelerated again back to ground potential by the same d-c voltage. The stripping process in the second foil has long been well known and is essentially 100 percent efficient at the energies we are interested in.

Besides the obvious advantage of producing twice as much energy with a given voltage, the system has the important practical advantage that both ion source and target are at or near ground potential. The only part at high voltage above ground is the stripping foil. These features should result in a much smaller and cheaper machine.

Survey of Work to Date

Construction of the quarter-scale model has been completed, including the ion source, accelerating column, vacuum system, and 500 kv. cascade rectifier. The parts have been separately tested, and testing with a beam is imminent. There has been some doubt that an electrode system with this geometry (positive electrode between two negative electrodes) would hold high voltage in a vacuum. It was thought that secondary electron multiplication and electron trapping in the potential valley might result in a discharge at a relatively low voltage. However it was found that the accelerating column held voltage at least as well as with single-ended geometry and apparently better; thus one of the major hurdles has been passed.

The 500 kv. rectifier constructed uses conventional hot cathode tubes with r-f filament heating . However, student thesis work has indicated the eventual elimination of hot-cathode rectifiers in megavolt d-c power supplies by means of cold-cathode vacuum tubes. Selenium rectifiers are generally undesirable in voltage multiplying circuits in this range. Test of field-emission diodes[2] have given promise that a practical sealed off rectifier tube can be made which will have an inverse voltage rating of 100 kv. or more with an average current rating of a few milliamperes.

Another thesis[3] has followed a different lead. A unique type of gas conduction occurs when a perforated anode between two cathodes is placed in a d-c magnetic field oriented parallel to the electric field. Conduction

2. Wharton, C.B., Field Emission Rectifier Characteristics, M.S. Thesis, University of California, June 1952.

3. Krause, O.H., A Study of Plasma Discharge in a Magnetic Field, M.S. Thesis, University of California, June 1952.

occurs at pressures hundreds of times lower than those required for conventional gas conduction. Thus far the only application has been as a vacuum gauge (Penning or Phillips ion gauge). This type of gas-conduction tube has unilateral conductivity with zero back current, and has a low forward drop and starting voltage (around 300 volts). Theory indicates an inverse of 100 kv. or more. Preliminary tests were made up to 30 kv. at which sparking around the glass occurred. When sealing-off problems are solved, it should be a useful rectifier for megavolt d-c power supplies. A small permanent magnet is sufficient to supply the magnetic field.

This being the first progress report on this project to appear in this publication, many things are included for completeness which are only briefly mentioned in order to avoid undue length. More details will be furnished in future issues.

<div align="right">J.R. Woodyard</div>

XII. ADMINISTRATION

In connection with work under contract numbers W33(038)-ac-26649 and AF33(616)-495 Col. R.S. Carter, Messrs. Wm.H. Nelson, F.E. Wenger, R. Slater and A.K. Jackson of Wright Air Development Center visited this Laboratory. Mr. C. Pierce, U.S.A.F. Development Office, Research and Development Command also visited here.

XIII.   REPORTS, PAPERS, AND TALKS

13.1   REPORTS ISSUED:

Under Contract N7-onr-29529

D.J. Angelakos,   "A Coaxial Line Filled with Two Non-Concentric Dielectrics", Technical Report, Series No. 60 Issue No. 102

A.E. Ratkevich,   "Properties of Large Slot Antennas", Technical Report, Series No. 60, Issue No. 104

Under Contracts Nos. W 19(122)ac-38 and W 33(038)ac-16649

F.B. Wood,   " The Coupled Q and the Shift in Resonant Frequency of Some Resnatron Anode Resonators", Technical Report, Series No. 1, Issue No. 65-a

Under University Sponsorship

G.L. Matthaei,   " Some Techniques for Network Synthesis", Technical Report, Series No. 60 Issue No. 103

D.C. Stinson,   " Resonant Frequencies of A Radial Line", Technical Report, Series No. 60, Issue No. 105

13.2   REPORTS UNDER PREPARATION:

Under Contract N7-onr-29529

R.W. Bickmore,   " Flush-Mounted Omni-Directional Annular-Slot Antennas", Technical Report Series No. 60**

D.J. Angelakos,   " Flush-Mounted Cardioid-Pattern Antennas", Technical Report Series No. 60

F.D. Clapp,   " Semi-Flush-Mounted Cardioid-Pattern Antenna for the 225-400 MC. Band", Technical Report Series No. 60

R.W. Bickmore,   " Radiation Pattern Synthesis with Annular Apertures", Technical Report Series No. 60

G.L. Matthaei,   " Matching Networks For Annular Slot Antennas" Technical Report Series No. 60**

Under Contract W 33-(038)-ac-16649

P.H. Kafitz,   " Arc-Cathodes in Power Oscillator Tubes", Technical Report Series No. 60

Under University Sponsorship

L.M. Silva,   " Non-Linear Optimization of Relay Servo-Mechanisms", Technical Report Series No. 60

**To be issued as combined reports